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# **Report on the Use of Sidewall Sprinklers and Water Mist Nozzles for Primary Damage Area (Fire) Cooling**

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14. ABSTRACT  The objective of this test series was to identify and characterize sidewall sprinklers and water mist nozzles that can thermally manage (i.e., prevent flashover and reduce the intensity of the fire) the primary damage area following a missile hit. The key variables that were investigated are: spray characteristics, flow rate, nozzle location, fire size, vent size, perburn time, and compartment configuration (i.e., obstructed vs nonobstructed). The results of the test discussed in this report indicate a potential risk with the low pressure nozzle. This risk is manifested in lower cooling capacity and resulting potential increase in water flow.					
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# REPORT ON THE USE OF SIDEWALL SPRINKLERS AND WATER MIST NOZZLES FOR PRIMARY DAMAGE AREA (FIRE) COOLING

## 1.0 INTRODUCTION

Significantly reduced manning requirements for DD(X) make it imperative that other means be sought to extinguish and prevent the spread of shipboard fires. One of the technologies being considered is the use of water spray to thermally manage the primary damage area (fire) (PDA(F)) following a missile hit. Thermal management is defined as the ability of a water mist/sprinkler system to maintain the temperatures in a compartment or PDA(F) below a specified value. These values may be based on flashover suppression ( $<500^{\circ}\text{C}$  ( $932^{\circ}\text{F}$ )) [1], fire spread ( $<250^{\circ}\text{C}$  ( $482^{\circ}\text{F}$ )) [2,3], or tenability. Following an actual missile hit, the primary objective of the system would be to prevent flashover by maintaining compartment temperatures below  $500^{\circ}\text{C}$  ( $932^{\circ}\text{F}$ ). It is also desirable, for the system to be capable of limiting temperatures to less than  $250^{\circ}\text{C}$  ( $482^{\circ}\text{F}$ ) to prevent fire spread to spaces adjacent to the primary damage area (APDA(F)).

The Naval Sea Systems Command (PMS 500) has developed a risk mitigation program to augment and support the development of the DD(X) Autonomic Fire Suppression System (AFSS). Included in this program is a series of tests, being conducted at the Chesapeake Bay Detachment (CBD) of the Naval Research Laboratory, to evaluate candidate nozzles for the PDA cooling application. The tests will evaluate candidate sprinkler and low, intermediate, and high-pressure water mist nozzles.

For the purposes of this report, the National Fire Protection Association's *Standard on Water Mist Fire Protection Systems* (NFPA 750) definitions of water mist will be used [4]. NFPA 750 defines water mist as a water spray for which the diameter of 99% of the droplets for the flow-weighted cumulative volumetric distribution of water is less than  $1000\ \mu\text{m}$ . NFPA 750 further classifies water mist systems based on the pressures exerted on the distribution piping. A high-pressure system is a water mist system where the distribution piping is exposed to pressures of 500 psi (34.5 bar) or more. An intermediate pressure system is a system that is exposed to pressures between 175 psi (12.1 bar) and 500 psi (34.5 bar) and a low-pressure system is defined as a system where the distribution piping experiences pressures less than 175 psi (12.1 bar). For the purposes of this investigation, all nozzles not classified as water mist nozzles were considered sprinklers.

## 2.0 OBJECTIVE

The objective of this test series was to identify and characterize sidewall sprinklers and water mist systems with the potential to thermally manage the PDA post-hit fire environment. The goal was to down-select nozzles for evaluation under real scale fire conditions on the ex-USS *Shadwell*. The key variables quantified were: fire size, vent size, flow rate, spray characteristics (nozzle type), preburn time and compartment configuration (obstructed/unobstructed).

### 3.0 TEST SETUP

#### 3.1 Test Compartment

A steel compartment, measuring 9.1 m x 9.1 m x 4.6 m high (30 ft x 30 ft x 15 ft high), located at the CBD facility, was utilized for this test series (Fig. 1). The test compartment is constructed of 1.5 m x 3.0 m (5.0 ft x 10.0 ft) steel plates. Two of these plates were removed with one plate reinstalled vertically, resulting in a vent opening 1.5 m (5.0 ft) wide and 3.0 m (10.0 ft) high. The second plate was divided and arranged to provide three different vent sizes. These vents provided the primary source of ventilation air to support combustion in the compartment.

#### 3.2 Fire Scenarios

Test fires were created by spraying heptane into a large, 1.0 m x 2.0 m (3.3 ft x 6.6 ft), pan located on the floor of the compartment. Flat spray nozzles (Bete Model FF) operating at 2.8 bar (40 psi) were used to achieve the necessary fuel flow rates for the fire sizes desired. The nozzles, operating pressures, measured fuel flow rates, and theoretical fire sizes are summarized in Table 1. Fuel was supplied from a nitrogen pressurized tank located outside the test enclosure.

**Table 1. – Spray fire summary**

Bete Nozzle No.	Operating Pressure (bar (psig))	Fuel Flowrate (LPM (gpm))	Theoretical Fire Size (MW)
FFO65	2.8 (40)	3.6(0.95)	1.8
FF104	2.8 (40)	9.1(2.4)	4.6

#### 3.3 Candidate Nozzles

Characteristics of the candidate nozzles, shown in Fig. 2, are summarized in Table 2. Table 2 identifies the manufacturer, model number, operating characteristics and nozzle classification. The Spraying Systems 7N is a 7-nozzle cluster composed of one #26 nozzle and pin in the center, and six #2 nozzles with #18 pins on the perimeter.

The nozzles were installed as shown in Fig. 3. The CBD fire truck was capable of providing 2835 Lpm (750 gpm) at 13.7 bar (200 psi) and was used to supply the sidewall sprinkler nozzle. Water for the other candidate nozzles was supplied through a manifold containing four pressure washers. Each pressure washer was capable of providing 23.8 Lpm (6.3 gpm) at 68.9 bar (1000 psi).

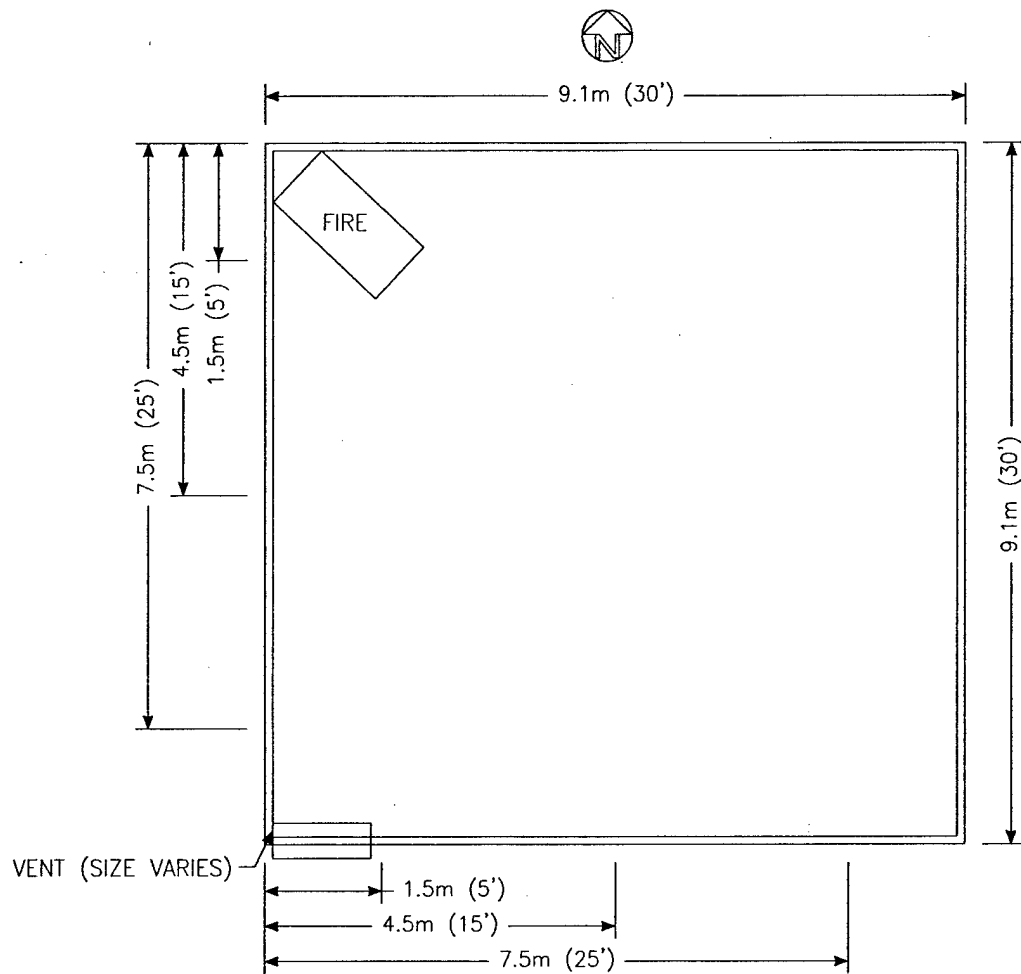


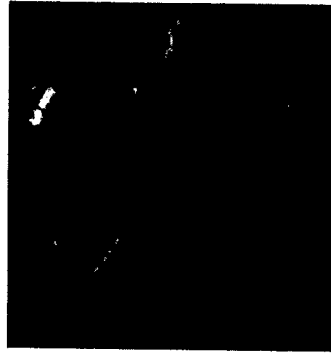
Fig. 1 – Test Compartment



Bete FF125



Bete NF30



Spraying Systems FF



Tyco AM18



Tyco Sidewall Sprinkler



Marioff S10



Spraying Systems 7N

Fig. 2 - Candidate Nozzles

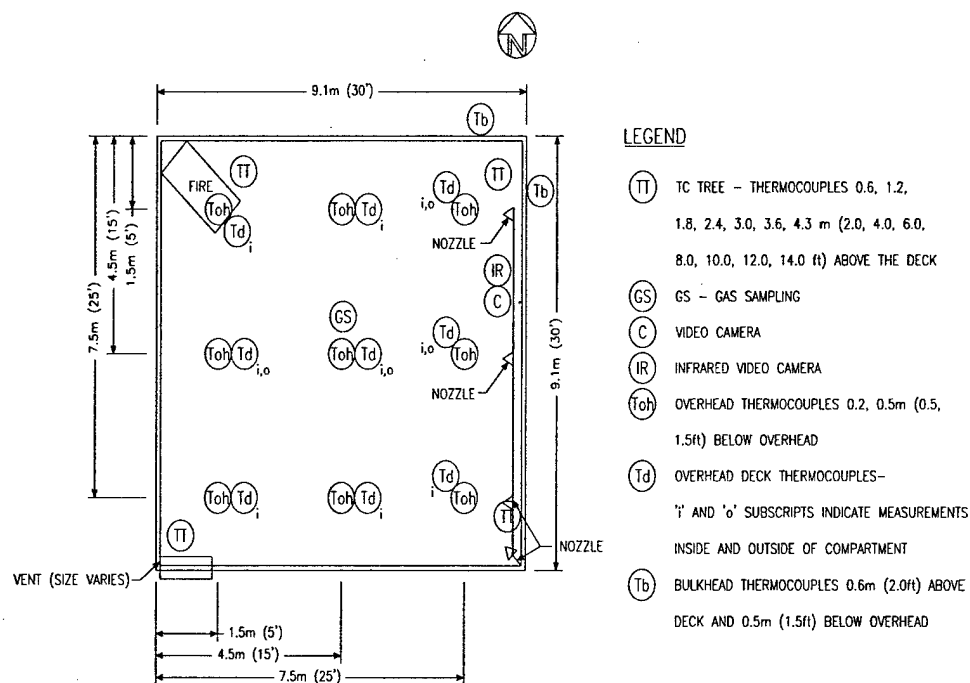


Fig. 3 – Instrumentation layout

**Table 2. - Candidate Nozzles**

Nozzle Classification	Nozzle	K-factor (Lpm/bar <sup>1/2</sup> (gpm/psi <sup>1/2</sup> ))	Operating Pressure (bar (psi))	Flowrate (Lpm (gpm))
Sprinkler	Universal Model A - EC Sidewall Sprinkler	80.7 (5.6)	3.45 (50)	149.9 (39.6)
	Bete FF125	5.5 (0.39)	10.3 (150)	18.2 (4.8)
	Bete NF30	6.7 (0.47)	10.3 (150)	22.0 (5.8)
Low Pressure Water Mist	Tyco AM18	9.0 (0.62)	10.3 (150)	28.9 (7.6)
	Spraying Systems FF	10.8 (0.76)	10.3 (150)	35.2 (9.3)
Intermediate Pressure Water Mist	Tyco AM18	9.0 (0.62)	17.2 (250)	37.1 (9.8)
	Spraying Systems 7N	6.1 (0.42)	34.5 (500)	35.6 (9.4)
High Pressure Water Mist	Marioff S10	3.3 (0.23)	68.9 (1000)	27.5 (7.3)
	Spraying Systems 7N	6.1 (0.42)	68.9 (1000)	50.3 (13.3)

### 3.4 Instrumentation

The instrumentation layout is shown in Fig. 3. Nine pairs of overhead air thermocouples and four thermocouple trees were placed throughout the test area to measure air temperatures. The overhead air thermocouples were located at 0.2 m (0.5 ft) and 0.5 m (1.5 ft) below the overhead. Each thermocouple tree consisted of seven thermocouples spaced 0.6 m (2.0 ft) apart, starting 0.6 m (2.0 ft) above the deck. In addition, thermocouples were placed throughout the PDA to measure the overhead surface temperatures. These surface thermocouples were placed on the inside of the roof at the same nine positions as the overhead thermocouples and on the outside of the roof at four of these positions. Surface temperatures were also measured on the inside and outside of the North and East walls, 0.6 m (2.0 ft) above the deck and 0.5 m (1.5 ft) below the overhead, 2.4 m (4.0 ft) away from the northeast corner. Oxygen, carbon monoxide, and carbon dioxide concentrations were measured in the center of the compartment 0.6 m (2.0 ft) below the overhead. Pressure transducers were used to monitor the water system and fuel spray system pressures. In addition to these measurements, infrared and video cameras were positioned in the northeast area of the enclosure to monitor the fire.

### 3.5 Test Procedures

Tests were initiated and terminated from the Control Module trailer. Prior to initiation, all openings to the test compartment were secured, except for the vent opening. Data acquisition was initiated two minutes prior to ignition of the fuel, marking the start of the test. After ignition, the fire was allowed to burn freely for a predetermined time before the mist/sprinkler system was activated. In most tests, the preburn time was seconds. In some tests the impact of preburn time was investigated with a 180 second preburn.

Each test continued until the fire was extinguished or steady state conditions were reached. After the test was completed, the fire was secured and the water system continued to discharge to cool the space. Once the space was cool, the water system was secured and the compartment was ventilated to clear the space of combustion gases.

#### **4.0 MEASURES OF PERFORMANCE**

The primary measures of performance for this test series were the ability of the nozzles to cool the compartment to prevent flashover (i.e., temperatures less than 500°C (932°F) and to limit fire spread to adjacent compartments (i.e., temperatures less than 250°C (482°F)). Since the initial tests discussed in this report did not produce temperatures above 500°C (932°F), only the 250°C (482°F) measure will be discussed in this report. The ability to extinguish the fires was also used as a measure of performance.

#### **5.0 RESULTS AND DISCUSSION**

This report provides selected data for the tests conducted thus far in this test series. A more detailed analysis of the data will be provided in the final report. The tests can be separated into nozzle screening and performance characterization tests. The nozzle screening tests, summarized in Table 3, were used to screen the candidate nozzles and facilitate a down select for further testing. The objective of screening some of the candidates early in the test series was to focus testing on the most promising candidates. The performance characterization tests, summarized in Table 4, were used to obtain data on the ability of the remaining candidates to adequately cool the PDA(F) under a variety of conditions.

The results of the nozzle screening and performance characterization tests are summarized in Tables 5 and 6, respectively. These tables show the average steady-state temperature measured for the thermocouple trees and the overhead thermocouples located 0.5 m (1.5 ft) below the overhead. The average thermocouple tree temperature was calculated by averaging the steady-state temperatures at each elevation of all four thermocouple trees for the 60 seconds prior to securing the fuel spray. In some cases, there was evidence of direct water spray on thermocouples causing artificially low measurements. These thermocouples were not included in the average values. The average overhead temperature was calculated by averaging the steady-state temperatures for all of the overhead thermocouples. Steady-state conditions were reached when there was no longer any significant change in temperature. In tests where the fire was extinguished, conditions did not reach steady-state conditions. Temperatures are not provided for these tests.

**Table 3. Single Nozzle, Screening Tests**

Test ID	Vent Size	Fire Size	Preburn Time (sec)	Nozzle	Pressure (bar (psi))	Comments
PDA_001	Medium	4 MW	N/A	None	N/A	Baseline Test
PDA_002	Medium	4 MW	20	AM18	10.3 (150)	
PDA_003	Medium	4 MW	20	NF30	10.3 (150)	
PDA_004	Medium	4 MW	20	SSFF	10.3 (150)	
PDA_005	Medium	4 MW	20	FF125	10.3 (150)	
PDA_006	Medium	4 MW	20	Sprinkler	1.5 (22)	
PDA_007	Medium	4 MW	20	Sprinkler	3.4 (50)	
PDA_008	Small	1.5 MW	N/A	None	N/A	Baseline Test
PDA_009	Small	1.5 MW	20	Sprinkler	3.4 (50)	
PDA_010	Small	1.5 MW	20	AM18	10.3 (150)	
PDA_011	Small	1.5 MW	20	NF30	10.3 (150)	
PDA_012	Small	1.5 MW	20	SSFF	10.3 (150)	
PDA_013	Small	1.5 MW	20	FF125	10.3 (150)	
PDA_014	Small	1.5 MW	20	AM18	17.2 (250)	
PDA_015	Small	1.5 MW	20	S10	68.9 (1000)	
PDA_017	Small	1.5 MW	20	7N	68.9 (1000)	
PDA_018	Small	1.5 MW	20	7N	34.5 (500)	
PDA_019	Medium	4 MW	20	7N	68.9 (1000)	
PDA_020	Medium	4 MW	20	S10	68.9 (1000)	
PDA_021	Medium	4 MW	20	Sprinkler	5.2 (75)	

**Table 4. Performance Characterization Tests**

Test ID	Vent Size	Fire Size	Preburn Time (sec)	Nozzle	Pressure (bar (psi))	Locations				Obstructed Fire	Comments
						(o = Open; x = Blocked)					
						North	Center	South	Southeast		
PDA_001	Medium	4 MW	N/A	None	N/A	x	x	x	x	No	Baseline Test
PDA_002 <sup>1</sup>	Medium	4 MW	20	AM18	10.3 (150)	x	x	x	o	No	
PDA_010 <sup>1</sup>	Small	1.5MW	20	AM18	10.3 (150)	x	x	x	o	No	
PDA_015 <sup>1</sup>	Small	1.5MW	20	S10	68.9 (1000)	x	x	x	o	No	
PDA_020 <sup>1</sup>	Medium	4 MW	20	S10	68.9 (1000)	x	x	x	o	No	
PDA_026	Medium	4 MW	20	AM18	10.3 (150)	o	o	o	x	No	
PDA_027	Medium	4 MW	180	AM18	10.3 (150)	o	o	o	x	No	
PDA_028	Medium	4 MW	20	AM18	10.3 (150)	x	o	o	x	No	
PDA_029	Medium	4 MW	20	AM18	10.3 (150)	o	x	o	x	No	
PDA_030	Medium	4 MW	20	AM18	10.3 (150)	o	o	x	x	No	
PDA_031	Medium	4 MW	180	AM18	10.3 (150)	o	x	o	x	No	
PDA_032	Large	4 MW	20	AM18	10.3 (150)	o	x	o	x	No	
PDA_033	Large	4 MW	20	AM18	10.3 (150)	x	o	o	x	No	
PDA_035	Large	4 MW	20	S10	68.9 (1000)	o	x	o	x	No	
PDA_036	Medium	4 MW	20	AM18	10.3 (150)	x	o	x	x	No	
PDA_038	Medium	4 MW	180	AM18	10.3 (150)	x	o	x	x	No	
PDA_040	Medium	4 MW	20	AM18	10.3 (150)	o	o	o	x	Yes	
PDA_041	Medium	4 MW	20	AM18	10.3 (150)	o	x	o	x	Yes	
PDA_042	Medium	4MW	20	S10	68.9 (1000)	o	x	o	x	Yes	
PDA_044	Medium	4 MW	20	S10	68.9 (1000)	o	o	o	x	No	
PDA_046	Medium	4 MW	180	S10	68.9 (1000)	o	o	o	x	No	
PDA_047	Large	4 MW	N/A	None	N/A	x	x	x	x	No	Baseline Test

**Note:** <sup>1</sup>These tests are also included as nozzle screening tests.

**Table 5. Results of Nozzle Screening Tests**

Test	Vent Size	Fire Size (MW)	Nozzle	Nozzle Pressure (bar (psi))	Steady-State Temperature (°C)		Comments
					TC Trees	OH Air	
PDA_001	Medium	4 MW	None	None	346	470	Baseline Test
PDA_002	Medium	4 MW	AM18	10.3 (150)	290	444	
PDA_003	Medium	4 MW	NF30	10.3 (150)	297	451	
PDA_004	Medium	4 MW	SSFF	10.3 (150)	303	410	
PDA_005	Medium	4 MW	FF125	10.3 (150)	305	448	
PDA_006	Medium	4 MW	Sprinkler	1.5 (22)	291	472	
PDA_007	Medium	4 MW	Sprinkler	3.4 (50)	274	444	
PDA_008	Small	1.5 MW	None	N/A	201	260	Baseline Test
PDA_009	Small	1.5 MW	Sprinkler	3.4 (50)	139	207	
PDA_010	Small	1.5 MW	AM18	10.3 (150)	143	203	
PDA_011	Small	1.5 MW	NF30	10.3 (150)	184	272	
PDA_012	Small	1.5 MW	SSFF	10.3 (150)	168	237	
PDA_013	Small	1.5 MW	FF125	10.3 (150)	201	284	
PDA_014	Small	1.5 MW	AM18	17.2 (250)	142	221	
PDA_015	Small	1.5 MW	S10	68.9 (1000)	155	247	
PDA_017	Small	1.5 MW	7N	68.9 (1000)	152	224	
PDA_018	Small	1.5 MW	7N	34.5 (500)	187	279	
PDA_019	Small	1.5 MW	7N	68.9 (1000)	273	440	
PDA_020	Medium	4 MW	S10	68.9 (1000)	294	465	
PDA_021	Medium	4 MW	Sprinkler	5.2 (75)	195	286	

Table 6. Results of Performance Characterization Tests

Test	Vent Size	Fire Size	Preburn Time (sec)	Nozzle	Nozzle Pressure (bar (psi))	Nozzle Locations				Steady-State Temperatures (°C)		Extinguishment Time (sec)	Comments
						(o = Open; x = Blocked)				TC Trees	OH Air		
						North	Center	South	South-East				
PDA_001	Medium	4 MW	n/a	None	n/a	x	x	x	x	346	470		Baseline test
PDA_002	Medium	4 MW	20	AM18	10.3 (150)	x	x	x	o	290	444		
PDA_010	Small	1.5MW	20	AM18	10.3 (150)	x	x	x	o	143	203		
PDA_015	Small	1.5MW	20	S10	68.9 (1000)	x	x	x	o	155	247		
PDA_020	Medium	4 MW	20	S10	68.9 (1000)	x	x	x	o	294	465		
PDA_026	Medium	4 MW	20	AM18	10.3 (150)	o	o	o	x	148	254		
PDA_027	Medium	4 MW	180	AM18	10.3 (150)	o	o	o	x	233	345		
PDA_028	Medium	4 MW	20	AM18	10.3 (150)	x	o	o	x	269	375		
PDA_029	Medium	4 MW	20	AM18	10.3 (150)	o	x	o	x	232	397		
PDA_030	Medium	4 MW	20	AM18	10.3 (150)	o	o	x	x	209	385		
PDA_031	Medium	4 MW	180	AM18	10.3 (150)	o	x	o	x	226	397		
PDA_032	Large	4 MW	20	AM18	10.3 (150)	o	x	o	x	228	400		
PDA_033	Large	4 MW	20	AM18	10.3 (150)	x	o	o	x	215	366		
PDA_035	Large	4 MW	20	S10	68.9 (1000)	o	x	o	x	234	386		
PDA_036	Medium	4 MW	20	AM18	10.3 (150)	x	o	x	x	302	442		
PDA_038	Medium	4 MW	180	AM18	10.3 (150)	x	o	x	x	330	458		
PDA_040	Medium	4 MW	20	AM18	10.3 (150)	o	o	o	x	182	315		Obstructed fire
PDA_041	Medium	4 MW	20	AM18	10.3 (150)	o	x	o	x	204	370		Obstructed fire
PDA_042	Medium	4 MW	20	S10	68.9 (1000)	o	x	o	x	-	-	228	Obstructed fire
PDA_044	Medium	4 MW	20	S10	68.9 (1000)	o	o	o	x	-	-	186	
PDA_046	Medium	4 MW	180	S10	68.9 (1000)	o	o	o	x	-	-	250	
PDA_047	Large	4 MW	n/a	None	n/a	x	x	x	x	399	440		Baseline test

As noted above, thermocouples directly sprayed by water were not included in these calculations.

## **5.1 Nozzle Screening Tests**

Conditions for the nozzle screening tests were similar for each test. A single nozzle was positioned 0.6m (2.0 ft) below the overhead in the southeast corner of the enclosure aiming directly at the fire in the northwest corner. All fires were unobstructed with a 20 second preburn time.

With the exception of Test PDA\_021 (sprinkler at 5.2 bar (75 psi)), there were only modest differences in the overhead and tree temperature measurements for the 4 MW scenarios between the nozzles. Among the other nozzles, there appear to be two groupings. The AM18, S10, Spraying Systems FF, 7N, and sprinkler at 3.4 bar (50 psi) show more cooling than the NF30, FF125, and sprinkler at 1.5 bar (22 psi). The differences are noticeable, but not dramatic. The sprinkler at 3.4 bar (50 psi) performed well. However, a flowrate of 131 Lpm (34.6 gpm) for a system designed to operate for 60 minutes was considered prohibitively high and sprinklers were not considered for further evaluation. Although as effective as some of the other nozzles in the screening tests, the Spraying Systems FF and 7N nozzles were not considered further because the spray angle was less than 20° degrees, which was considered too narrow for this application. Based on the modest temperature reductions measured in the nozzle screening tests, the Tyco AM18 and Marioff S10 were considered for further testing to determine their ability to cool the primary damage area.

## **5.2 Performance Characterization Tests**

The performance characterization tests focused on the AM18 and S10 nozzles. Since the 4 MW fire had an average overhead temperature of 470°C (878°F), it did not produce temperatures sufficient to evaluate the flashover prevention criteria of 500°C (932°F). The main focus of the evaluation in this report is the ability of the systems to reduce temperatures, particularly below the 250°C (482°F) threshold. Larger fire sizes will be evaluated as the testing progresses to examine flashover prevention. The results of the tests completed thus far are discussed below.

A limited number of scenarios have been conducted for both the AM18 and S10 nozzles. Comparing the scenarios where both nozzles were evaluated (i.e., PDA\_026 vs. PDA\_044, PDA\_027 vs. PDA\_046, PDA\_041 vs. PDA\_042, and PDA\_032 vs. PDA\_035), the S10 performed better than the AM18 nozzle. In three of the four tests, the S10 nozzles extinguished the fire, while the AM18 nozzle did not extinguish any fires. By extinguishing the fire the S10 nozzle was able to reduce the compartment temperatures very quickly, whereas the use of the AM18 nozzle resulted in a steady-state burning condition.

Even though the AM18 nozzle did not extinguish any fires, it did demonstrate an ability to cool the compartment. For example, in Test PDA\_026 with three nozzles flowing, the average overhead temperature was reduced from 470°C (878°F) to 254°C (489°F). This was a significant reduction in temperature from the baseline value and just slightly higher than the

250°C (482°F) measure of performance. However, based on the results of Tests PDA\_028, PDA\_029, and PDA\_030, it appears that the AM18 performance degrades substantially as the number of nozzles is reduced. With two nozzles, the average overhead temperatures ranged from 375°C (707°F) to 397°C (747°F). Reducing the number of nozzles reduced the flow rate of water into the compartment.

A limited number of tests have been conducted with the large vent configuration. A preliminary review of the data shows a reduction in performance for the AM18 nozzle when the vent size was increased from the medium vent (PDA\_029) to the large vent (PDA\_032). This may be an indication that the AM18 nozzle is not effectively controlling the flow of air into the compartment; however, additional testing with the large vent area is needed to investigate this further.

For both the AM18 and S10 nozzles, the nozzles were more effective at limiting compartment temperatures for the 20-second preburn tests than for the 180 second preburn. For three AM18 nozzles, the average overhead temperatures increased from 254°C (489°F) for the 20 second preburn (PDA\_026) to 345°C (653°F) for the 180 second preburn (PDA\_027). For the two nozzle AM18 configuration, the temperatures were the same; 397°C (747°F) for the 20 second (PDA\_029) and 180 second (PDA\_031) preburn times. Given the potential time required to reconfigure a damaged fire main, the 180-second preburn time is more realistic than the 20-second time.

Data for the obstructed fire scenario tests are inconclusive. In one case (PDA\_029 vs. PDA\_041) the addition of the obstruction improved performance. The steady state temperature was 397°C (747°F) for the unobstructed fire and 370°C (698°F) for the obstructed fire. In another instance (PDA\_026 vs. PDA\_040) the obstruction had a negative impact on performance with the temperature increasing from 254°C (489°F) for the unobstructed to 315°C (599°F) for the obstructed.

## **6.0 PRELIMINARY CONCLUSIONS**

The objective of this test series was to identify and characterize sidewall sprinklers and water mist nozzles that can thermally manage (i.e., prevent flashover and reduce the intensity of the fire) the primary damage area following a missile hit. The key variables that were investigated are: spray characteristics, flowrate, nozzle location, fire size, vent size, preburn time and compartment configuration (i.e., obstructed vs. unobstructed). This preliminary report provides selected data for the tests conducted to date in the test series. A more detailed analysis of the data will be provided in the final report.

Two of the candidate nozzles, the Tyco AM18 and the Marioff S10, were selected for further evaluation based on the results of the nozzle screening tests. The ability of these nozzles to thermally manage the space is being tested under a variety of conditions.

Although the analysis is ongoing, some preliminary conclusions can be drawn from the data obtained to date:

- The performance characterization tests conducted did not produce temperatures sufficient to evaluate the flashover prevention criteria of reducing overhead temperatures below 500°C (932°F)
- The S10 nozzle extinguished the fire in three of four tests, whereas the AM18 nozzle did not extinguish any. In these three tests, the compartment temperature was reduced below 250°C (482°F) quickly after extinguishment.
- The AM18 nozzle was unable to extinguish any fires or to reduce temperatures below 250°C (482°F). Under some conditions (i.e., three nozzles with medium vent and 20 second preburn), the AM18 nozzle was able to provide significant cooling of the compartment, nearly reducing temperatures to 250°C (482°F).
- Reducing the number of nozzles/flowrate into the compartment significantly reduced the ability of the AM18 nozzle to cool the compartment. Performance of the AM18 nozzle may be heavily dependent on the number of nozzles that survive in the PDA.
- The AM18 nozzle was less effective when the vent size was increased.
- The performance of both the AM18 and S10 nozzles decreased as the preburn time was extended from 20 to 180 seconds. For the AM18 nozzle, this was manifested in increased steady-state temperature. For the S10 nozzle, the fire extinguishment time increased.

The results of the tests discussed in this report indicate a potential risk with the low pressure AM18 nozzle. This risk is manifested in lower cooling capacity and resulting potential increase in water flow. Additional analysis is required to quantify this risk. This will include tests with the S10 nozzle under conditions similar to those used with the AM18 nozzle and discussed in this report. Tests will also include Class A materials to evaluate the impact of fuel type on performance, large fire sizes to evaluate flashover prevention, and thermal activation of nozzles.

## 7.0 REFERENCES

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